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The comparison of various foam polymer types in composite sandwich panels subjected to full scale air blast loading

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Abstract

Full scale air blast testing has been performed on a range of polymeric foam composite panels. These panels employed glass fibre reinforced polymer (GFRP) face-sheets with different polymer foam cores, namely: Styrene acrylonitrile (SAN); Polyvinylchloride (PVC) and Polymethacrylimide (PMI). The three sandwich panels were all subjected to 100 kg TNT equivalent blast loading at a stand-off distance of 15 m, and the responses of the panels were measured using Digital Image Correlation (DIC). The extent of damage in the sandwich panels was then inspected via post-blast sectioning, and it was found that the SAN core suffered the least damage, and the PMI suffered the most. The DIC showed that the deflection of the SAN core sandwich panel was much less than the other two foam polymer cores, due to less damage meaning a greater stiffness was retained. All blast research to date is part of a programme sponsored by the Office of Naval Research (ONR).

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Keywords: Foam polymer effects, blast loading, digital image correlation.

1. Introduction

Polymeric foam sandwich panels are of interest in military applications due to their low radar signature, as well as possessing tailorable mechanical properties and having low density. The blast resistance of these sandwich composites is of importance in all military applications, and some research has been performed on SAN core

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sandwich panels by Arora, Hooper and Dear [1], where sandwich panels were subjected to 30 kg C4 charges. Testing was also performed on graded density sandwich panels by Gardner, Wang and Shukla [2], in which a shock tube was implemented to simulate blast loading. Numerous studies into analytical response predictions to blast loading have been made, and a notable example of this is by Hoo Fatt and Palla [3]. Here PVC foam core sandwich panels were subjected to blast loading, and the responses were split into core crushing and bending to cause core damage. Further analytical solutions into PVC were performed by Andrews and Moussa [4] to determine the different failure modes of the sandwich panels: face-sheet wrinkling; face-sheet tensile failure and core shear cracking. PMI foam cores have been investigated by Shipsa and Zenkert [5] by using low velocity impact and investigating the residual strength of the sandwich panels. Large scale blast testing, similar to the tests presented in this research, were also performed by Arora et al [6] where 100 kg TNT equivalent charges were used in order to compare the responses of sandwich panels with glass fibre reinforced polymer (GFRP) and carbon fibre reinforced polymer (CFRP) face-sheets to explosive loading. As is illustrated in the literature Styrene Acrylonitrile (SAN), Polyvinyl Chloride (PVC) and Polymethacrylimide (PMI) are all common foam polymer types used in the application of composite sandwich panels, and this research compares glass fibre reinforced polymer (GFRP) sandwich composites of equal core density and thickness in order to determine the different dynamic blast responses of the different foams. The foam sandwich panels were subjected to full scale air blast testing, and their responses were recorded using high speed cameras for 3D Digital Image Correlation (DIC). The sandwich panels were then section after blast loading, in order to assess the amount of core cracking and debonding present. This paper details the experimental setup, the instrumentation and the results of the DIC and the post-blast inspection. Conclusions are then drawn into the suitability of these foam polymer types for blast applications.

2. Materials

This research considered the blast resistance of polymeric foam sandwich composite panels with 2 mm thick GFRP face-sheets, to full scale blast loading. The comparative study included three different foam polymers: SAN, PVC and PMI. All three foam cores had a density of 100 kg/m^3 and a thickness of 40 mm. The responses of the sandwich panels were expected to be similar due to similar known mechanical properties, but with the dynamic behavior of these polymeric foams bearing little research, the blast tolerance was to be determined in this work.

3. Test Parameters

This section provides details of the air blast setup, the high speed camera instrumentation, and the post-blast damage inspection technique.

3.1 Blast Test Setup

All air blast testing in this research project is performed at GL DNV, RAF Spadeadam, Cumbria, UK. The charge used for blast loading was a 100 kg Nitomethane explosive, which has a TNT equivalence of 1. The charge was situated at 15 m from the test panels, and a schematic of the test pad layout is provided in Fig. 1. An external camera was situated at approximately 25 m from the cubicle front, to ensure that no unexpected events took place during testing, such as debris hitting the test panel, and a steel plate was situated underneath the charge to ensure an elastic foundation for the blast wave. Furthermore static and reflected pressure gauges were situated at the same stand-off distance as the sandwich panels. The test cubicle consisted of a reinforced steel front with two test panels bolted in to it, and large concrete culverts behind the steel front to provide a rigid foundation for the steel cubicle front. The test panels were bolted on to the front of the test cubicle with 20 x M10 bolts through the thickness of the sandwich panel, with steel plates either side around the edges, and steel tubes to prevent core crushing, as shown in Fig. 2. This provided quasi-built in boundary conditions.

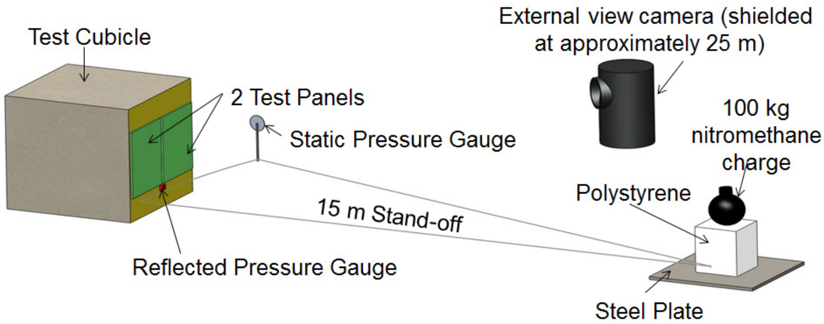

Fig. 1. Schematic of the blast test layout.

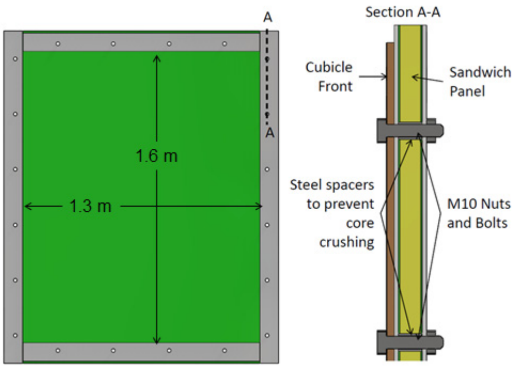

Fig. 2. Clamping arrangement of the sandwich panel on to the cubicle front.

3.2 Instrumentation

In order to track the displacement and strain of the three sandwich panels during testing, two Photron SA1.1 high speed cameras were positioned behind the test panels, and their positions calibrated for 3D DIC. The panel response was then recorded at 1 megapixel resolution, and 5400 frames per second. The high speed cameras were triggered via an open transistor-transistor-logic (TTL) circuit attached to the side of the explosive, and upon detonation the ionised air made the TTL circuit thus triggering the cameras. The two sets of images were then processed using Aramis DIC analysis software, in order to provide the out of plane displacement and strain on the back face of the sandwich panels.

3.3 Post-blast damage assessment

To quantify the damage suffered by the sandwich panels during blast loading they were cut into 16 sections, and the edges inspected. The amount of debonding between the face-sheets and core along each edge was then estimated visually and the number of core cracks counted to allow a comparison of damage in the three test sandwich panels. The damage was also mapped on schematics of the panels, in order to see the damage patterns during the blast tests.

4. Test Results

In this section of the paper the results of the DIC processing are presented, as well as the post-blast sectioning to allow a discussion of the suitability of the three polymer foams to be made in the subsequent sections.

4.1 DIC Results

By performing 3D DIC it is possible to track the out of plane displacement (U_Z) of the sandwich panels during blast loading, as well as recording the in-plane maximum principal strain (ε_{max}), both of which have been extracted in this research. Fig. 3 provides the out of plane displacement (U_Z) and maximum principal strain (ε_{max}) for the SAN, PVC and PMI core sandwich panels, measured using DIC from the high speed camera images. In all cases the first two contour plots of maximum principal strain (ε_{max}) depict high strain areas along the vertical edges, which is caused by early core cracking leading to large localised bending at this region, resulting in large strains on the back face-sheet of the sandwich panel. The out of plane displacement (U_Z) plots of the sandwich panels show discontinuities of gradient along one edge of the sandwich panel in the later stages of loading, and this is also due to core cracking causing high localised bending. The out of plane displacement (U_Z) is also around 10 mm lower in the case of the SAN polymer core than in the other two test panels. The rectangular areas of high strain in the maximum principal strain (ε_{max}) contour plots are indicative of core cracking as well because the cracks around the edges reduce the deflection on the outside of the panels, so only the central region experience the high bending.

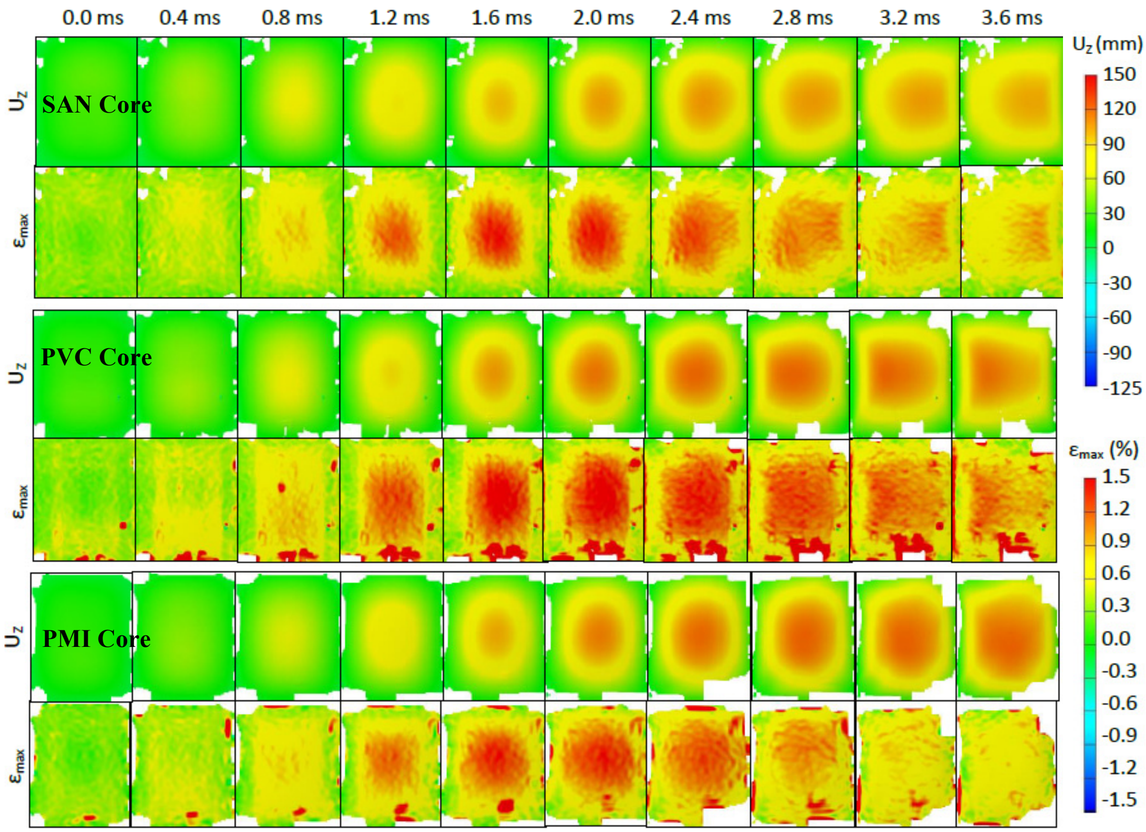

Fig. 3. The out of plane displacement (U_Z) and maximum principal strain (ε_{max}) of the three sandwich panels, measured using DIC.

4.2 Post-blast sectioning results

In order to assess the damage suffered during blast loading, the three sandwich panels were sectioned in to 16 pieces after blast loading, to inspect the edges for damage. The amount of debonding between the face-sheets and the core was then estimated, and the number of cracks propagating through the core thickness counted. Fig. 4 illustrates the debonding and core cracking map for the SAN foam core, and Fig. 5 provides this for the PVC foam core. The locations of front face-sheet compressive cracks are also shown in these figures. Due to high amounts of core cracking and debonding it was not possible to section the PMI core sandwich panel, but the damaged region of the panel (including a mixture of debonding and cracking) accounted for around 75% of the sandwich panel. From the post blast damage inspection it was determined that the SAN core suffered significantly less debonding and core cracking than the PVC and PMI cases, and as a result of less core cracking also suffered less front face-sheet failure.

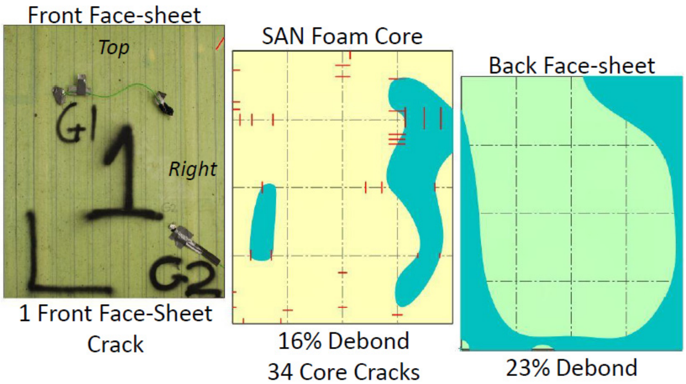

Fig. 4 Schematic of the debonded areas of the sandwich panel (blue shading) and of the locations of core shear cracks (red dashes) in the SAN foam core sandwich panel.

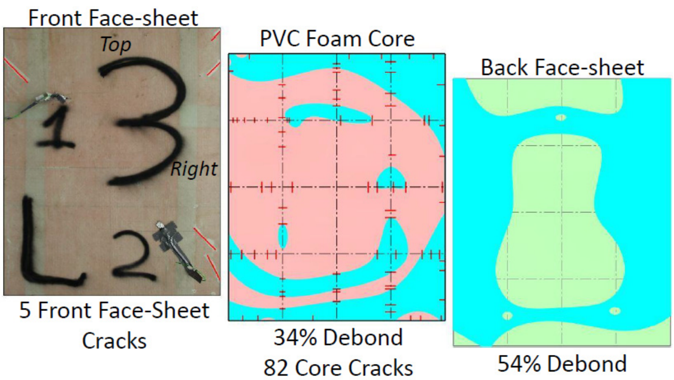

Fig. 5 Schematic of the debonded areas of the sandwich panel (blue shading) and of the locations of core shear cracks (red dashes) in the PVC foam core sandwich panel.

5. Discussion

This blast test research presented here aimed to compare three common core materials used in GFRP sandwich panels: SAN; PVC and PMI. All three sandwich panels contained 40 mm thick 100 kg/m^3 foam cores, with similar known mechanical properties. During blast loading the responses were captured using DIC, and this illustrated the possibility to observe sub-surface damage in these tests using this technique, as high back face-sheet strain was visible in the location of core cracking. The SAN foam polymer retained more stiffness during loading, due to less cracking, and deflected 10 mm less than the other two sandwich panels, reaching about 90 mm maximum deflection. The sub-surface core cracking in the sandwich panels can also be observed via discontinuities in the out of plane displacement profiles measured with DIC, and it was found that these were much more pronounced in the PMI case than the other two, implying more damage. Upon post-blast sectioning and inspection it was discovered that the total debonded area of the SAN sandwich panel, across both interfaces between the face-sheets and core, was around 20%. In the PVC case this was about 44% and in the PMI case was over 60%. Furthermore 34 through thickness core cracks were observed in the SAN core, 82 in the PVC core and more than 200 in the PMI core. This allows the conclusion to be drawn that the SAN foam core sandwich panel suffers much less core and interface damage than the PVC and PMI cores, resulting in much less deflection and front face-sheet cracking due to it retaining a high stiffness. The PMI case suffers particularly severe core cracking during blast loading, resulting in high amounts of debonding, and severe compressive front face-sheet cracks.

6. Conclusion

The conclusions of this research performed into varying GFRP sandwich core foam polymer types can be summarised into the following points:

- The use of DIC maximum principal strain measurements on the back face of the sandwich panel can provide an early indication of sub-surface damage due to high localised bending.
- Discontinuities in the displacement profile across the back face-sheet of the sandwich panel provide an assessment of the extent and location of sub-surface core damage.
- Significant core damage causes severe drops in stiffness, resulting in compressive front face-sheet cracking.
- SAN foam polymer suffers the least amount of damage out of the three polymer types, resulting in less deflection and fewer front face-sheet cracks.
- PMI suffers heavy core cracking, leading to significant debonding in the interfaces between the core and the face-sheets, and leads to a lot of front face-sheet cracking.

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